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# Exploratory study of shrinkage of the diffraction cone for the generalized BFKL pomeron

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## Abstract

In color dipole gBFKL dynamics, we describe the emerging gBFKL phenomenology of a subasymptotic energy dependence of the diffraction slope and discuss possibilities of testing the gBFKL predictions in exclusive photo- and electroproduction of vector mesons  $V$  at HERA. A substantial shrinkage of the diffraction cone  $\gamma^*p \rightarrow Vp$  processes from the CERN/FNAL to HERA range of energy  $W$  is predicted. This subasymptotic shrinkage is faster than expected from the small slope of pomeron's Regge trajectory  $\alpha'_{\mathbf{P}}$ . We point out that the diffraction slope is a scaling function of  $(m_V^2 + Q^2)$ , what relates production of different vector mesons.

Is the QCD pomeron a fixed or moving singularity? Can the two options be distinguished experimentally in hard diffraction processes at HERA? These pressing issues are addressed in this paper to.

The early discussion on the BFKL (Balitsky-Fadin-Kuraev-Lipatov [1]) pomeron centered on the scaling  $\alpha_S = \text{const}$  approximation with infinite propagation radius  $R_c$  of (massless) gluons. In this approximation, for a lack of the dimensional scale, the BFKL pomeron is a fixed cut in the  $j$ -plane:  $-\infty < j \leq \alpha_{\mathbf{P}}(t) = \alpha_{\mathbf{P}}(0) = 1 + \Delta_{\mathbf{P}}$ , which also implies the energy-independent diffraction slope at  $t = 0$ . The scaling approximation is not self-contained, though, because the diffusion BFKL Green's function makes high-energy behavior even at short distances increasingly sensitive to the nonperturbative large-distance contribution [1-3]. The introduction of running QCD coupling  $\alpha_S(r)$  into the generalized BFKL (gBFKL) equation for color dipole cross section [3] further amplifies an intrusion of large-distance effects. Furthermore, in our Ref. [4] we have shown that breaking of scale invariance by a running  $\alpha_S(r)$  complemented by the finite gluon propagation radius  $R_c$  [3], profoundly changes the very nature of the gBFKL pomeron from a *fixed* cut of the scaling  $\alpha_S = \text{const}$  approximation to a *moving* cut with the finite Regge slope  $\alpha'_{\mathbf{P}}$  of the pomeron trajectory. This conclusion [4] derives from the fact that gBFKL diffraction slope  $B(\xi, r)$  for scattering of a color dipole of size  $r$  has the asymptotic Regge growth

$$B(\xi, r) = B(0, r) + 2\alpha'_{\mathbf{P}}\xi, \quad (1)$$

where  $\xi = \log(W^2/s_0)$ ,  $W$  is the c.m.s. energy and  $s_0 = m_p^2$  in hadronic scattering,  $s_0 = Q^2$  and  $\xi = \log(\frac{1}{x})$  in deep inelastic scattering and in leptonproduction of vector mesons  $s_0 = m_V^2 + Q^2$ . In the gBFKL dynamics [3-5] a dimensionful  $\alpha'_{\mathbf{P}}$  is a nonperturbative quantity related to the nonperturbative infrared parameter of the model - the gluon propagation radius  $R_c$ . For the preferred  $R_c = 0.27 \text{ fm}$ , quite a small  $\alpha'_{\mathbf{P}} = 0.072 \text{ GeV}^{-2}$  is found (the Regge phenomenology of soft hadronic scattering suggests <sup>1</sup>  $\alpha'_{soft} \sim 0.2 \text{ GeV}^{-2}$  [6,7]). A strong argument [3-5,8-10] for using running  $\alpha_S(r)$  is that only in this case the short-distance (Leading-Log $Q^2$ ) limit of the gBFKL equation matches the GLDAP equation [11].

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<sup>1</sup>Here one must bear in mind that because of the so-called absorption corrections the observed  $\alpha'_{soft}$  is typically larger than the Regge slope  $\alpha'_{eff}$  in the bare pomeron amplitude [7].

A dramatic impact of scale invariance breaking on the intercept  $\Delta_{\mathbf{P}}$  found in [3] (for earlier work see [9]) has recently been confirmed in [10,12] using a very different technique.

How the finding that the gBFKL pomeron is a moving cut can be tested experimentally? Based on a solution of the gBFKL equation [4] for  $B(\xi, r)$ , in this paper we discuss the emerging gBFKL phenomenology of the diffraction slope. First, with plausible and partly tested boundary conditions, we show that at attainable subasymptotic energies (comprising the HERA energies), the local Regge slope  $\alpha'_{eff}(\xi, r) = \frac{1}{2}\partial B(\xi, r)/\partial \xi$  is much larger than the above cited  $\alpha'_{\mathbf{P}}$  and is surprisingly close to  $\alpha'_{soft} \sim 0.2 \text{ GeV}^{-2}$ . Second, we find  $B(\xi, r)$  of a magnitude which is intriguingly close to the experimental determinations. Third, we discuss scaling properties of  $B(\xi, r)$  which relate diffraction slope for different exclusive reactions  $\gamma^* p \rightarrow V p$  ( $V = \rho^0, \omega^0, \phi^0, J/\Psi, \Upsilon, \dots$ ) and can be tested at HERA. Here we focus on the fact [13,14] that exclusive vector meson production probes the dipole cross section  $\sigma(\xi, r)$ , and  $B(\xi, r)$  and  $\alpha'_{eff}(\xi, r)$  thereof, at  $r \sim r_S$ , where the scanning radius

$$r_S \approx \frac{6}{\sqrt{Q^2 + m_V^2}}. \quad (2)$$

We recall first the gBFKL equation [3,5] for color dipole cross section  $\sigma(\xi, r)$ :

$$\frac{\partial \sigma(\xi, r)}{\partial \xi} = \mathcal{K} \otimes \sigma(r, \xi) = \frac{3}{8\pi^3} \int d^2 \vec{\rho}_1 \mu_G^2 \left| g_S(R_1) K_1(\mu_G \rho_1) \frac{\vec{\rho}_1}{\rho_1} - g_S(R_2) K_1(\mu_G \rho_2) \frac{\vec{\rho}_2}{\rho_2} \right|^2 [\sigma(\xi, \rho_1) + \sigma(\xi, \rho_2) - \sigma(\xi, r)] . \quad (3)$$

Here the kernel  $\mathcal{K}$  is related to the flux of Weizsäcker-Williams (WW) soft gluons generated by the  $\bar{q}$ - $q$  color dipole source,  $\vec{r}$  is the  $\bar{q}$ - $q$  separation and  $\vec{\rho}_{1,2}$  are the  $q$ - $g$  and  $\bar{q}$ - $g$  separations in the two-dimensional impact parameter plane,  $K_\nu(x)$  is the modified Bessel function,  $\vec{\mathcal{E}}(\vec{\rho}) = \mu_G g_S(\rho) K_1(\mu_G \rho) \frac{\vec{\rho}}{\rho} = -g_S(\rho) \vec{\nabla}_\rho K_0(\mu_G \rho)$  describes a Yukawa screened transverse chromoelectric field of the relativistic quark and

$$\mu_G^2 \left| g_S(R_1) K_1(\mu_G \rho_1) \frac{\vec{\rho}_1}{\rho_1} - g_S(R_2) K_1(\mu_G \rho_2) \frac{\vec{\rho}_2}{\rho_2} \right|^2 = |\vec{\mathcal{E}}(\vec{\rho}_1) - \vec{\mathcal{E}}(\vec{\rho}_2)|^2 \quad (4)$$

gives a flux (a modulus of the Poynting vector) of WW soft gluons in the  $q\bar{q}g$  state and  $\frac{9}{8}[\sigma(\xi, \rho_1) + \sigma(\xi, \rho_2) - \sigma(\xi, r)]$  is a change of cross section for the presence of the WW gluon [5]. The running QCD charge  $g_S(r) = \sqrt{4\pi\alpha_S(r)}$  must be taken at the shortest relevant distance

$R_i = \min\{r, \rho_i\}$  and in the numerical analysis [3] an infrared freezing  $\alpha_S(q^2) \leq 0.82$  has been imposed on the three-flavor, one-loop  $\alpha_S(q^2) = 4\pi/[9 \log(q^2/\Lambda^2)]$  with  $\Lambda = 0.3 \text{ GeV}$ . The preferred choice  $R_c = 0.27 \text{ fm}$  gives  $\Delta_{\mathbf{P}} = 0.4$  [4] and leads to a very good description [15] of the HERA data on the proton structure function at small  $x$ .

The nonperturbative infrared parameter  $R_c = 1/\mu_G$  has a very clear meaning of a correlation (propagation, Ukawa screening) radius for perturbative gluons. The above infrared regularization is not unique, but the crucial transversality property of WW gluons holds independent of the specific model for screening and only the numerical results can somewhat change. At  $r, \rho_{1,2} \ll R_c$  and in the  $\alpha_S = \text{const}$  approximation, the scaling BFKL equation is obtained ([3,5], see also Mueller and Patel [16]), in the Leading-Log $Q^2$  regime of  $r \ll \rho_{1,2} \ll R_c$ , the gBFKL Eq. (3) matches [3,5] the GLDAP equation (see also [9,10]).

Generalization of (3) to the equation for diffraction slope  $B(\xi, r)$  proceeds as follows [4]: If the impact-parameter representation,  $\sigma(\xi, r) = 2 \int d^2 \vec{b} \Gamma(\xi, r, \vec{b})$  and the diffraction slope  $B(\xi, r)$  at  $t = 0$  equals  $B(\xi, r) = \frac{1}{2} \langle \vec{b}^2 \rangle = \lambda(\xi, r)/\sigma(\xi, r)$ , where

$$\lambda(\xi, r) = \int d^2 \vec{b} \vec{b}^2 \Gamma(\xi, r, \vec{b}), \quad (5)$$

$\Gamma(\xi, r, \vec{b})$  is the profile function and  $\vec{b}$  is the impact parameter defined with respect to the center of the  $q\bar{q}$  dipole. In the  $q\bar{q}g$  state, the  $qg$  and  $\bar{q}g$  dipoles have the impact parameter  $\vec{b} + \frac{1}{2}\vec{\rho}_{2,1}$  and, undoing the impact parameter integrations in (3), one finds:

$$\begin{aligned} \frac{\partial \Gamma(\xi, r, \vec{b})}{\partial \xi} = \mathcal{K} \otimes \Gamma(\xi, r, \vec{b}) &= \frac{3}{8\pi^3} \int d^2 \vec{\rho}_1 \mu_G^2 \left| g_S(R_1) K_1(\mu_G \rho_1) \frac{\vec{\rho}_1}{\rho_1} - g_S(R_2) K_1(\mu_G \rho_2) \frac{\vec{\rho}_2}{\rho_2} \right|^2 \\ &\times [\Gamma(\xi, \rho_1, \vec{b} + \frac{1}{2}\vec{\rho}_2) + \Gamma(\xi, \rho_2, \vec{b} + \frac{1}{2}\vec{\rho}_1) - \Gamma(\xi, r, \vec{b})]. \end{aligned} \quad (6)$$

It is convenient to separate from  $B(\xi, r)$  a purely geometrical component  $\frac{1}{8}r^2$  due to the color dipole's elastic form factor and consider  $\eta(\xi, r) = \lambda(\xi, r) - \frac{1}{8}r^2\sigma(\xi, r)$ . Then, the calculation of the moment (5) in (6) leads to an inhomogeneous equation

$$\begin{aligned} \frac{\partial \eta(\xi, r)}{\partial \xi} &= \frac{3}{8\pi^3} \int d^2 \vec{\rho}_1 \mu_G^2 \left| g_S(R_1) K_1(\mu_G \rho_1) \frac{\vec{\rho}_1}{\rho_1} - g_S(R_2) K_1(\mu_G \rho_2) \frac{\vec{\rho}_2}{\rho_2} \right|^2 \\ &\times \left\{ \eta(\xi, \rho_1) + \eta(\xi, \rho_2) - \eta(\xi, r) + \frac{1}{8}(\rho_1^2 + \rho_2^2 - r^2)[\sigma(\rho_2, \xi) + \sigma(\rho_1, \xi)] \right\} \\ &= \mathcal{K} \otimes \eta(\xi, r) + \beta(\xi, r), \end{aligned} \quad (7)$$

$$\beta(\xi, r) = \mathcal{L} \otimes \sigma(\xi, r) = \frac{3}{64\pi^3} \int d^2\vec{\rho}_1 \mu_G^2 \left| g_S(R_1) K_1(\mu_G \rho_1) \frac{\vec{\rho}_1}{\rho_1} - g_S(R_2) K_1(\mu_G \rho_2) \frac{\vec{\rho}_2}{\rho_2} \right|^2 \times (\rho_1^2 + \rho_2^2 - r^2) [\sigma(\rho_2, \xi) + \sigma(\rho_1, \xi)] . \quad (8)$$

A homogeneous Eq. (7) coincides with Eq. (3), which has several consequences. First, if  $\sigma_1(\xi, r)$  and  $\eta_1(\xi, r)$  are solutions of Eqs. (3),(7), then  $\eta_2(\xi, r) = \eta_1(\xi, r) + \Delta b \cdot \sigma_1(\xi, r)$  with  $\Delta b = \text{const}$  also is a solution of Eq. (7) with  $B_2(\xi, r) = B_1(\xi, r) + \Delta b$ . Second, the Regge growth of  $B(\xi, r)$  can be driven only by the inhomogeneous term  $\beta(\xi, r)$ .

The detailed arguments for  $\alpha'_{\mathbf{P}} \neq 0$ , based on properties of eigenvalues of the gBFKL equation (3) and of the kernel  $\mathcal{L}$  have been presented in [4] and need not be repeated here. We only cite the order of magnitude estimate

$$\alpha'_{\mathbf{P}} \sim \frac{3}{16\pi^2} \int d^2\vec{r} \alpha_S(r) \mu_G^2 r^2 K_1^2(\mu_G r) \sim \frac{3}{64\pi} R_c^2 \alpha_S(R_c) , \quad (9)$$

which clearly shows the connection between the dimensionful  $\alpha'_{\mathbf{P}}$  and the nonperturbative infrared parameter  $R_c$ . We determine  $\alpha'_{\mathbf{P}}$  from the numerical solution of Eqs. (3,7,8) as the  $\xi \rightarrow \infty$  limit of  $\alpha'_{eff}(\xi, r)$ . The resulting  $R_c$  dependence of  $\alpha'_{\mathbf{P}}$  is shown in Fig. 1 and is very steep in the opposite to a weak  $R_c$ -dependence of the intercept  $\Delta_{\mathbf{P}}$  found in [3].

The gBFKL dipole cross section  $\sigma(\xi, r)$  sums the Leading-Log( $W^2$ ) multigluon production cross sections. Consequently, as a realistic boundary condition for the gBFKL dynamics one can take the two-gluon exchange Born amplitude

$$\begin{aligned} \text{Im}A(\xi_0, r, \vec{q}) &= \frac{16\pi}{9} \int d^2\vec{k} \frac{\alpha_S(\vec{k}^2) \alpha_S(\kappa^2)}{[(\vec{k} + \frac{1}{2}\vec{q})^2 + \mu_G^2][(\vec{k} - \frac{1}{2}\vec{q})^2 + \mu_G^2]} \\ &\times [\cos(\frac{1}{2}\vec{q}\vec{r}) - \cos(\vec{k}\vec{r})] \cdot [G_1(\vec{q}) - G_2(\vec{k} + \frac{1}{2}\vec{q}, -\vec{k} + \frac{1}{2}\vec{q})] . \end{aligned} \quad (10)$$

Here we use the normalization  $\text{Im}A(\xi_0, r, \vec{q} = 0) = \sigma(\xi_0, r)$ ,  $\kappa^2 = \min\{\vec{k}^2, C^2 r^{-2}\}$ ,  $C \sim 1.5$  [17],  $\vec{k} \pm \frac{1}{2}\vec{q}$  are the momenta of exchanged gluons,  $G_1(\vec{q})$  and  $G_2(\vec{k}_1, \vec{k}_2)$  are the single- and two-quark form factors of the proton probed by gluons. The former is customarily approximated by, and the latter in simple quark models can be related to, the charge form factor of the proton (for instance, see [18,19]). A very good quantitative gBFKL description of the HERA data on the small- $x$  proton structure functions is obtained [15] if the Born cross section Eq. (10) with  $R_c = 0.27 \text{ fm}$  is taken as a boundary condition for the gBFKL

equation (3) at the Bjorken variable  $x_0 = 0.03$ , i.e., at  $\xi_0 = \log \frac{1}{x_0} = 3.5$ . Hereafter we only consider  $R_c = 0.27 \text{ fm}$ .

The Born approximation for  $B(\xi_0, r)$ , shown in Fig. 2, has nice properties which admit a simple interpretation. First, for  $r \lesssim R_c$ , the Born amplitude (10) is dominated by perturbative  $k^2 \sim r^{-2} \gtrsim \mu_G^2$  for which  $G_2(\vec{k}, -\vec{k})$  vanishes. Consequently,  $A(\xi, r, \vec{q}) \propto G_1(\vec{q})$  and  $B(\xi_0, r \ll R_c) = \frac{1}{3} \langle R_1^2 \rangle_p$ , which is a generic perturbative result and holds beyond the above simplified derivation. Second, the  $r$  dependence of the Born approximation  $B(\xi_0, r)$  can be cast in a very symmetric and intuitively appealing form

$$B(\xi_0, r) = \frac{1}{3} \langle R_1^2 \rangle + \frac{1}{8} r^2 + \delta B = \frac{1}{2} \langle r_{cms}^2 \rangle_{beam} + \frac{1}{2} \langle r_{cms}^2 \rangle_{target} + \delta B. \quad (11)$$

The found small departure from the dipole size dominated slope (11),  $|\delta B| \lesssim 1 \text{ GeV}^{-2}$ , is evidently related to the small  $R_c^2 \approx 2 \text{ GeV}^{-2} \ll \frac{2}{3} \langle R_{ch}^2 \rangle$ . One can argue that for the same reason the  $r$  dependence of  $B(\xi_0, r)$  must be insensitive to details of the infrared regularization. The negligible  $\delta B$  in Eq. (11) implies a simple boundary condition  $\eta(\xi_0, r) \approx B(\xi_0, 0) \sigma(\xi_0, r)$  and an energy independent contribution  $\approx B(\xi_0, 0)$  to the diffraction slope  $B(\xi, r)$ . Consequently, the energy dependence of  $B(\xi, r)$  and  $\alpha'_{eff}(\xi, r)$  are governed by the inhomogeneous term  $\beta(\xi, r)$  of Eq. (8) and only depend on the input dipole cross section (10), which already has successfully been tested [15] against the DIS data. The gluon-probed radius of the proton  $R_1$  is a phenomenological parameter to be determined from the experiment. For the evaluation purposes, we approximate  $R_1$  by the proton charge radius  $R_{ch}$ :

$$B(\xi_0, r \ll R_c) \approx \frac{1}{3} \langle R_{ch}^2 \rangle_p \approx 5.8 \text{ GeV}^{-2}. \quad (12)$$

In Fig. 3 we present the effective Regge slope  $\alpha'_{eff}(\xi, r)$  which follows from the solution of coupled Eqs. (3,7,8) with the above described boundary conditions. At  $\xi \rightarrow \infty$ ,  $\alpha'_{eff}(\xi, r)$  tends to a  $r$ -independent  $\alpha'_{\mathbf{p}} = 0.072 \text{ GeV}^{-2}$ . The very slow onset of the limiting value  $\alpha'_{\mathbf{p}} = 0.072 \text{ GeV}^{-2}$  correlates nicely with the very slow onset of the gBFKL asymptotics of  $\sigma(\xi, r)$  and of the proton structure function [3,8,15]. Slight oscillations in  $\alpha'_{eff}(\xi, r)$  at small  $\xi$  are a consequence of the oscillatory  $r$ -dependence of large- $\nu$  eigenfunctions  $E(\nu, r)$  (for the related discussion see [3]).

The above results for  $\alpha'_{eff}(\xi, r)$  can be tested in exclusive diffractive processes  $\gamma^*p \rightarrow Vp$ . At fixed  $\xi$ , the dependence on the vector meson mass  $m_V$  and the photon virtuality  $Q^2$  is concentrated in Eq. (2) for the scanning radius  $r_S$  and we predict the same  $B(\xi, r_S)$  and  $\alpha'_{eff}(\xi, r_S)$  for all reactions with the same  $\xi$  and  $r_S$  and/or  $(m_V^2 + Q^2)$ , provided that  $r_S \lesssim R_V$  [14,20]. For instance,  $r_S(\Upsilon, Q^2 = 0) \approx r_S(J/\Psi, Q^2 \sim 120 \text{ GeV}^2) \approx r_S(\rho^0, Q^2 \sim 200 \text{ GeV}^2) \approx 0.13 \text{ fm}$ ;  $r_S(J/\Psi, Q^2 \sim 30 \text{ GeV}^2) \approx r_S(\rho^0, Q^2 \sim 60 \text{ GeV}^2) \approx 0.2 \text{ fm}$ ;  $r_S(J/\Psi, Q^2 = 0) \approx r_S(\rho^0, Q^2 \sim 20 \text{ GeV}^2) \approx 0.4 \text{ fm}$  and  $r_S(\rho^0, Q^2 \sim 3.5 \text{ GeV}^2) \approx 0.76 \text{ fm}$  (we refer to the dominant production of the longitudinally polarized  $\rho^0$  [14]). The hatched areas in Fig. 3 indicate a variation of  $\alpha'_{eff}(\xi, r)$  over the HERA range of *c.m.s* energy  $W = 50 - 200 \text{ GeV}$  (the higher values of  $\alpha_{eff}(\xi, r)$  correspond to a lower  $W$ ). Remarkably, at the HERA and lower energies, the subasymptotic  $\alpha_{eff}(\xi, r) \sim (0.15-0.2) \text{ GeV}^{-2}$  is quite large, close to  $\alpha'_{soft}$  and by the factor 2-3 larger than the asymptotic value  $\alpha'_{\mathbf{P}} = 0.072 \text{ GeV}^{-2}$ .

The results for the diffraction slope in an approximation (12) are presented in Fig. 4. According to Eqs. (2,11), the diffraction slope decreases with  $Q^2$  and the vector meson mass. The absolute value of  $B(\xi, r)$  depends on the assumed gluon probed radius of the proton  $R_1$ , whereas the rate of the shrinkage  $\alpha'_{eff}(\xi, r)$  does not. The experimental determination of  $\langle R_1^2 \rangle$  is of great interest by its own. For all the exclusive  $\gamma^*p \rightarrow Vp$  reactions we find a substantial rise of  $B(\xi, r_S)$ , by  $\sim 1.5 \text{ GeV}^{-2}$ , from the CERN/FNAL fixed target range of  $W \sim 10 \text{ GeV}$  to the HERA collider energy  $W \sim 100 \text{ GeV}$ . Here we have taken  $R_c = 0.27 \text{ fm}$ , the experimental measurement of this rise would be the best constraint on  $R_c$ .

The above analysis refers to the (infrared regularized) perturbative gBFKL scattering amplitude. For the description of semi-perturbative and soft scattering phenomena, one needs to complement the gBFKL dipole cross section by the soft nonperturbative, non-gBFKL, component  $\sigma^{(npt)}(\xi, r)$ , which at  $r \gtrsim R_c$  overwhelms the above discussed perturbative gBFKL cross section  $\sigma^{(pt)}(\xi, r)$  [14,15]. This non-gBFKL soft cross section has only a marginal effect on the proton structure function at large  $Q^2$  [15], but contributes substantially to vector meson production amplitudes unless  $r_S \lesssim R_c$  [14]. Of the above  $\gamma^*p \rightarrow Vp$  reactions, only a real (and a virtual) photoproduction of the  $\Upsilon$  and a virtual photoproduction of the  $J/\Psi$  at  $Q^2 \gtrsim 20 \text{ GeV}^2$  and of the  $\rho^0$  at  $Q^2 \gtrsim 40 \text{ GeV}^2$  are purely perturbative

processes. For instance, in real photoproduction of the  $J/\Psi$ , the nonperturbative soft contribution makes  $\sim 50\%$  of the photoproduction amplitude. Although the mechanism of this nonperturbative soft interaction is not well understood, the geometrical size dependence (11) could roughly be applicable also to a soft production mechanism (for an example of the nonperturbative model see [21]). Furthermore, because we find  $\alpha'_{eff} \sim \alpha'_{soft}$ , as a poor man's approximation, we can use the above gBFKL evaluations of the slope for the soft scattering too. The estimates of  $B(\xi, r_S)$  for a semi-perturbative real photoproduction of the  $J/\Psi$  and moderately virtual photoproduction of the  $\rho^0$ , shown in Fig. 4, assume this poor man's approximation.

The available data on the  $J/\Psi$  photoproduction are not yet conclusive. A direct selection of purely elastic events was performed only in the FNAL E401 experiment [22] with the result  $B(J/\Psi; Q^2 = 0) = 5.6 \pm 1.2 \text{ GeV}^{-2}$ . The CERN NMC result,  $B(J/\Psi; Q^2 = 0) = 5.0 \pm 1.1 \text{ GeV}^{-2}$ , comes from a sample which contains background excitation of the target proton [23]. These values of  $B(J/\Psi; Q^2 = 0)$  for  $W \sim 15 \text{ GeV}$  are consistent with our estimates shown in Fig. 4. At the present stage of HERA experiments, a direct rejection of proton excitation is not yet possible [24,25]. The model-dependent analysis of the first H1 data at  $\langle W \rangle = 90 \text{ GeV}$  gives estimates of  $B(J/\Psi; Q^2 = 0)$  ranging from 8.1 to 4.9  $\text{GeV}^{-2}$  [24], the first ZEUS data give  $B(J/\Psi; Q^2 = 0) = 4.5 \pm 1.4 \text{ GeV}^{-2}$  [25]. One needs the higher accuracy data from the both fixed target FNAL/CERN and the collider HERA experiments. Here one must bear in mind a well known rapid rise of the diffraction slope towards  $t = 0$  [26]. We calculate the diffraction slope at  $t = 0$ , whereas the experimental data on the vector meson production correspond to a slope evaluated over quite a broad range of  $t$ , typically up to  $|t| \lesssim 1 \text{ GeV}^{-2}$ , which may underestimate  $B(V; Q^2)$ . The ZEUS data on virtual photoproduction of the  $\rho^0$  mesons give  $B(\rho^0; 7 < Q^2 < 25 \text{ GeV}^2) = 5.1 + 1.2 - 0.9(stat) \pm 1.0(syst) \text{ GeV}^{-2}$  [27], which is close to the above cited  $B(J/\Psi; Q^2 = 0)$ , in agreement with our  $(m_V^2 + Q^2)$  scaling. This result is also consistent with the predicted decrease of  $B(\rho^0; Q^2)$  from real photoproduction in which  $B(\rho^0; Q^2 = 0) = 10.6 \pm 0.4(stat) \pm 1.5(syst) \text{ GeV}^{-2}$  [28].

To summarize, the purpose of the present paper has been an exploration of the phenomenology of forward diffractive scattering which emerges from the gBFKL dynamics.

The intrusion of large distance effects leads to a shrinkage of the diffraction cone driven by the nonperturbative slope of the pomeron's Regge trajectory  $\alpha'_{\mathbf{P}}$ . We presented the first evaluation of the energy dependence of the gBFKL diffraction slope. An interesting finding is a large subasymptotic value of the effective Regge slope  $\alpha'_{eff}(\xi, r)$ , which is by the factor  $\sim(2-3)$  larger than  $\alpha'_{\mathbf{P}}$ . For exclusive production of all the vector mesons at HERA, we find a substantial, by  $\sim 1.5 \text{ GeV}^{-2}$ , rise of the diffraction slope  $B(\gamma^* \rightarrow V)$  from the fixed target CERN/FNAL to the collider HERA energy. From the scanning property in vector meson production, we predict the scaling dependence on the variable  $(m_V^2 + Q^2)$ , which allows to relate diffracton slope for different reactions. Strong dependence of  $\alpha'_{\mathbf{P}}$  on the gluon propagation radius  $R_c$  makes the rise of the diffraction slope a sensitive probe of  $R_c$ .

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## Figure captions:

**Fig. 1** - The Regge slope  $\alpha'_{\mathbf{P}}$  of the pomeron trajectory vs. the propagation radius of gluons  $R_c$ .

**Fig. 2** - The solid line shows the diffraction slope  $B(\xi_0, r)$  for color dipole-proton scattering in the two-gluon exchange Born approximation. The dashed straight line shows the geometrical law Eq. (11) with. The difference between the dashed line and solid curve describes  $\delta B$ .

**Fig. 3** - The energy ( $\xi$ ) dependence of the effective Regge slope  $\alpha'_{eff}(\xi, r)$  vs.  $\xi = \log(1/x_{eff}) = \log[W^2/(Q^2 + m_V^2)]$  changing by  $\Delta\xi = 2$  from  $\xi = 5.5$  (the curve (a)) to  $\xi = 13.5$  (the curve (e)). The curve (f) is for  $\xi = 17.5$ . For reference, the curves (a), (b), (c), (d), (e) and (f) correspond to  $x_{eff} = W^2/(Q^2 + m_V^2) = 5 \cdot 10^{-3}, 7 \cdot 10^{-4}, 9 \cdot 10^{-5}, 1.25 \cdot 10^{-5}, 1.6 \cdot 10^{-7}$  and  $3 \cdot 10^{-8}$ , respectively. The horizontal line (g) shows the asymptotic value  $\alpha'_{\mathbf{P}} = 0.072 \text{ GeV}^{-2}$ . The hatched areas A – D show the range of variation of  $\alpha'_{eff}(\xi, r_S)$  over the HERA energy range  $W = (50-200) \text{ GeV}$  at a scanning radius  $r_S$  relevant to the reaction  $\gamma^* p \rightarrow Vp$  at the photon's virtuality  $Q^2$ : (A)  $r_S = 0.12 \text{ fm}$ ,  $\Upsilon(Q^2 \sim 0)$ , (B)  $r_S = 0.21 \text{ fm}$ ,  $J/\Psi(Q^2 \sim 30 \text{ GeV}^2)$ , (C)  $r_S = 0.4 \text{ fm}$ ,  $J/\Psi(Q^2 \sim 0)$  and  $\rho^0(Q^2 \sim 20 \text{ GeV}^2)$ , (D)  $r_S = 0.76 \text{ fm}$ ,  $\rho^0(Q^2 \sim 3.5 \text{ GeV}^2)$ .

**Fig. 4** - The c.m.s. energy  $W$  dependence of the diffraction slope  $B(\xi, r_S)$  at a dipole size (scanning radius)  $r_S$  relevant to different diffractive  $\gamma^* p \rightarrow Vp$  processes: (a)  $r_S = 0.12 \text{ fm}$ ,  $\Upsilon(Q^2 \sim 0)$ , (b)  $r_S = 0.21 \text{ fm}$ ,  $J/\Psi(Q^2 \sim 30 \text{ GeV}^2)$ , (c)  $r_S = 0.4 \text{ fm}$ ,  $J/\Psi(Q^2 \sim 0)$  and  $\rho^0(Q^2 \sim 20 \text{ GeV}^2)$ , (d)  $r_S = 0.76 \text{ fm}$ ,  $\rho^0(Q^2 \sim 3.5 \text{ GeV}^2)$ .

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